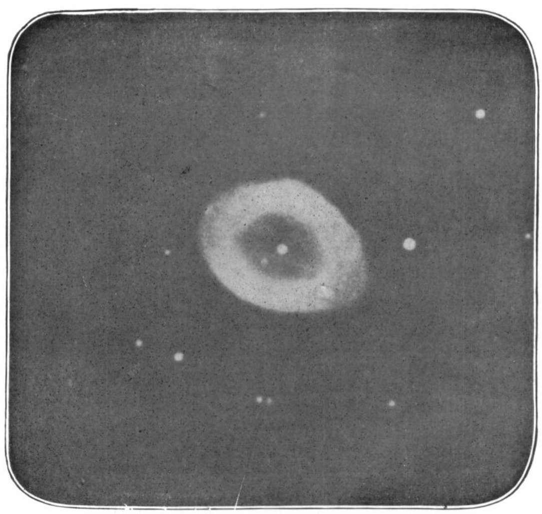

RING NEBULA IN *LYRA* (MESSIER 51).

BY J. E. KEELER.

(By courtesy of the Editors of the *Astrophysical Journal.*)

THE RING NEBULA IN *LYRA.*

By Burt L. Newkirk.

(Read before the Astronomical Society of the Pacific, November 28, 1903.)

Soon after sundown at this time of the year a bright bluish star may be seen in the northwest sky. It is the star *Vega,* the principal star of the constellation *Lyra,* and the brightest star of the northern hemisphere. The other stars of the constellation are inconspicuous. Near one of the fainter of these stars is situated the Ring Nebula in *Lyra,* the largest and finest of the annular nebulæ. (See plate.)

The nebula as it appears in the photograph is oval in shape, somewhat broader and less intense at the ends, and contains a star in the center. A careful examination of the original negative shows that what appears here as a plain ring devoid of fine detail is really a composite structure showing interlaced streamers of nebulosity.* As seen in a telescope of ten inches aperture, the ring is large and bright, but the central star, which is so conspicuous in this photograph, and indeed in all photographs of the nebula, is visible to the eye only with the help of two or three of the largest telescopes in the world. Mr. Barnard says that it is a very difficult object with the great telescopes of the Lick or Yerkes observatories. The ease with which this star, so difficult to see, can be photographed is due to the fact that its light is composed largely of waves from the violet region of the spectrum, which affect the photographic plate more strongly than they affect the retina of the eye. A longer exposure than that given the plate from which this reproduction is made shows the ring to be entirely filled with faint nebulosity. Professor Schaeberle† has recently made some photographs of the nebula, from a study of which he concludes that it is really a spiral nebula, and that the ring-like appearance is due simply to the fact that the wisps of nebulosity which characterize the spiral are too faint and closely wound to be observed ordinarily. If this opinion of Professor Schaeberle's is confirmed, it will be an important contribution to the subject of nebular forms and the study of the typical life-history of nebulæ, as I shall show later.

* Keeler, *Astroph. J.*, Vol. X, p. 193.

† Schaeberle, *A. J.*, Vol. XXIII, p 109 and 181.

Photography enjoys peculiar advantages in its application to the study of the structure of nebulæ, as compared with visual methods. It is safe to say that no eye has seen so much of the detailed structure of this nebula by direct visual observation as appears in the photograph of which this is a copy, taken with the Crossley reflector of the Lick Observatory by the late Director KEELER.

One who would gain a definite conception of the position this nebula occupies in the society of the heavens and its relation to the great plan of the universe must answer to himself the following questions: Where is it located? What are its physical characteristics and its composition? What has its life-history been, and what vicissitudes is it destined to undergo in ages to come?

First, where is it? How far is it from our Sun and his family of planets? Is its distance from us comparable to the distances of the stars, or is it immeasurably more remote, or is it perhaps a very near neighbor of ours? We shall see that it is in fact one of our celestial neighbors.

An investigation of the distance of a heavenly body is called a parallax determination. So far as I know, no nebula except this one has been made the subject of a successful parallax determination;* and of all the nebulæ of the skies the Ring Nebula in *Lyra* offers the most inviting opportunity to one wishing to determine a nebular parallax. It is the largest of the ring nebulæ, which fact gives countenance to the suspicion that it is nearer us than the average. The apparent size of a celestial object as seen from the Earth depends upon two things; its actual size and its distance from us. Since the Ring Nebula appears larger than other nebulæ of its class, it is then either actually larger than the other nebulæ or nearer to us than they are. Either alternative is, *a priori*, as probable as the other, and if the latter holds it would favor the choice of this nebula for a parallax determination, because the fact is that most celestial objects outside the Sun's system are so far away that their parallaxes are immeasurably small. Certainly not one star or nebula in a thousand has a parallax as large as a tenth of a second, and the usual result of a parallax investigation is simply to show that the object is so far away

* YOUNG'S *Manual of Astronomy*, 1902, § 604.

that its distance cannot be measured with the accuracy at present attainable. In choosing an object for a parallax investigation we ought therefore to fix upon one which we have reason to believe is nearer than the average if we hope for anything but a negative result. This is the only one of the nebulæ, with perhaps one exception, that has been found to show evidence of proper motion. Its proper motion tends to confirm the hypothesis of the proximity of the nebula. The relation between proper motion and parallax has been explained by Professor NEWCOMB* in a recent number of the *Astronomical Journal.* Moreover, the central star of this nebula offers a point of vantage for accurate micrometric measurement. This is a very great advantage, inasmuch as the indefinite and hazy character prevalent among nebulæ renders the refined measurements necessary for parallax determination practically impossible.

The investigation of the parallax of the central star of the Ring Nebula in *Lyra,* to which I have referred,† differs from other determinations of parallax only in the number of comparison-stars used, in the symmetry of their positions, and in a consequent simplification of the process of reduction of the measures, accompanied by a gain in accuracy. Instead of taking four to six such comparison-stars, as is generally done, sixteen were chosen. It was possible to measure sixteen distances on the photographic plate and carry through the reduction for the whole sixteen, with an increase of labor which was slight in comparison with the advantage gained in the precision of the result. The stars chosen were all faint and differing little in magnitude from the central star of the nebula. They were arranged in eight pairs, and the two stars of each pair were situated at about equal distances from the nebula star and in opposite directions. This symmetry of the position of the comparison-stars made possible the use of the short method of reduction mentioned above, making it unnecessary to apply special corrections for aberration or refraction, which effects a great saving of labor. Moreover, only three of the eight pairs of comparison-stars were chosen in the line of the major axis of the parallactic ellipse. There was a marked advantage in the diversity of the position-angles of the remaining pairs, as

* *A.J.*, Vol. XXII, p. 165

† Dissertation, University of Munich, 1902 (B. L. NEWKIRK).

this made it possible to investigate certain possible sources of error. The result was a parallax of about one tenth of a second, with a probable error of about one eighth of that amount, and an annual proper motion of fifteen hundredths of a second. That is, the radius of the Earth's orbit, as seen from the star, subtends an angle of one tenth of a second, or this star is about thirty-three light-years distant. If this central star actually forms a part of the nebula, and is not, as some have suggested, a star far this side of or far beyond the nebula, which merely happens to be projected upon the nebula as we see it,—supposing, I say, that this star is a part of the nebula, then we may say that the *nebula* is about thirty-three light-years away from us; i. e., it would take light thirty-three years to come to us from the nebula, traveling at the rate of one hundred and eighty-six thousand miles per second. Inasmuch as the great majority of the stars and nebulæ are certainly hundreds, and even thousands, of light-years away, we are justified in regarding the Ring Nebula in *Lyra* as one of our nearest celestial neighbors.

Knowing the distance of the nebula, and having the measures of its apparent dimensions as seen from the Earth, we can form an estimate of its actual size. Its longest diameter is about forty seconds,* which corresponds to an actual distance of four hundred times the radius of the Earth's orbit, or fourteen times the radius of *Neptune's* orbit. The smallest radius of the inside of the ring is fifteen seconds, corresponding to a distance equal to five times the radius of *Neptune's* orbit. Thus the whole of the solar system could be put into this ring and would have plenty of room to spare. I am speaking now, of course, of the ring of bright nebulosity shown in the picture. It has already been noted that longer exposures show the ring to be entirely filled with faint nebulosity.

It is to be presumed that the law of gravity holds there as it does in the solar system, and in that case the nebula may be in rotation about an axis coinciding with the axis of the ring, though this is not necessarily the case. This rotation would undoubtedly be very slow. How long it would take to accomplish a complete revolution cannot be stated without knowing the mass of the ring and of the central star, but we

* KEELER, *Astroph. J.*, Vol. X, p. 193.

might surmise that something like three thousand years would be required.* It must not be supposed that the whole ring rotates as a rigid body. This could not be the case. The particles composing the ring move about with a good deal of freedom, each in its own orbit, with occasional collisions, much as do the discrete pieces composing *Saturn's* rings.

The result of the determination of proper motion would lead us to believe that the Ring Nebula is moving along through space with a component of velocity perpendicular to the line of sight of about five miles per second, which is only about one fourth of the average stellar velocity.

It might be objected that this measurement of the distance does not apply to the nebula at all. It is not the nebula whose distance from the Sun's system has been measured, but the central star, and we have no conclusive evidence that the star belongs to the nebula. It might, as hinted at a moment ago, be some star a long distance from the nebula but in line with it as seen from the Earth, so that it only appears to be in the center of the nebula. In answer to this objection it can be urged that it would certainly be a very curious coincidence if this were the case. It would not be at all likely that a random star, having no connection with the nebula, would be so situated as to appear to us to be exactly in the center of the ring. I say it would be a curious coincidence if this were to occur in a single case, but much more so if it were to occur in a number of instances. There are other smaller nebulæ of the annular type, and most of these show faint stars in the center. Observers of experience† seem to think that all annular nebulæ have these central stars, only their faintness rendering them invisible in some instances. This alone is very convincing evidence in favor of the view that the central star of the Ring Nebula in *Lyra* is actually a part of the nebula. There is, however, corroborative evidence in the fact that an examination of the color of the central star shows it to be of a somewhat greenish tint, which color characterizes nebulæ rather than stars. Until very recently there was no instrument in existence with which the spectrum of this central star could be investigated with any

* Period of a satellite revolving about a body of five times the Sun's mass at a distance twelve times the semimajor axis of *Neptune's* orbit.

† BURNHAM, *Lick Obs. Pub.*, Vol. II, p. 159.

degree of accuracy, and so, for want of a better method, Mr. BARNARD adopted the following program.* He carefully focused the forty-inch telescope of the Yerkes Observatory on different stars and took the readings of the focal micrometer in each case. He found that for white stars the readings were all about the same, but there was a marked difference in the reading of the focal micrometer when the telescope was focused upon a gaseous nebula. As light of different colors comes to a focus at different distances from the lens, this was a rough method of testing the color or spectral character of the object pointed at. Then Mr. BARNARD pointed at the central star of the Ring Nebula in *Lyra* and focused carefully. He obtained the following results from the readings of the focal micrometer (the results are given in fractions of an inch): Neb.-Nuc., + 0.20; Neb.-star, + 0.30; Nucleus-star, + 0.10. This shows that the light of the central star differs from the light of an ordinary white star in partaking somewhat of the nature of the light of the nebula. At the time of his death, Professor KEELER was planning to adapt the Crossley reflector to the spectroscopic study of very faint stars, and he had particularly in mind the central star of the Ring Nebula in *Lyra*. This work has been carried forward under the direction of Professor CAMPBELL, and some results recently published by Mr. PALMER, of the Lick Observatory staff. Mr. PALMER† has found it possible to photograph the spectrum of the central star, which he finds to be continuous in that part of the spectrum where the bright lines of nebular light occur. This is not decisive evidence in favor of the claim that the central star is a part of the nebula, but it does not militate against the theory, which indeed needs no more evidence in its favor than has already been adduced.

The question as to the physical character and composition of the nebula next demands attention. It is a gaseous nebula. Its spectrum shows bright lines, indicating the presence of hydrogen and some other substance or substances not known to exist on the Earth or in the Sun or in any of the stars. This substance seems to be characteristic of gaseous nebulæ, and has therefore been called *nebulum*. The gas of which the nebula is composed is probably in a condition of great tenuity,

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* BARNARD, *Monthly Notices*, Vol. LX, p. 255. KEELER, *Astroph. J*, Vol. X, p. 193.

† *Astroph. J.*, Oct., 1903, p. 218.

like the upper regions of our atmosphere. The cause of its luminosity is a mystery. It is in all probability not due to heat. The presumption is, that the temperature of the nebula is not far above the absolute zero of interstellar space. The upper regions of our atmosphere often become luminous through electrical discharges, and the light emitted by nebulæ may perhaps be produced in this way. Sir NORMAN LOCKYER* proposes to account for the luminosity of nebulæ upon the theory that they are composed of swarms of meteorites in an atmosphere of hydrogen, and that the meteorites collide frequently, striking fire. There are, however, grave objections to this theory, especially in its application to ring nebulæ.

In former times many people believed this nebula to be an immense galaxy of stars. Sir WILLIAM HERSCHEL, who was the first to study nebulæ extensively, propounded the theory that all nebulæ were clusters of stars very far removed from the solar system, looking like bright clouds in the sky, because his telescope was not powerful enough to enable him to see them as individual stars. Many of the seeming nebulæ which he observed in the early part of his life were found later, with the help of a larger and more powerful telescope, to be clusters of faint stars. Thus he concluded quite naturally that a telescope powerful enough would show all nebulæ to be star-clusters. Now, stars are suns like the source of our light and heat, and it was the most natural step in the world to the conclusion that our Sun is but one of a galaxy of stars which make up a nebula, and that all nebulæ are such collections of suns or stars. It is apparent to any close observer that the stars visible on a clear evening are more thickly crowded together in the neighborhood of the Milky Way, and it is generally believed that our Sun is but one of a galaxy forming an immense ring, or disk, of stars. If one were removed to an immense distance from this galaxy it might look somewhat as the Ring Nebula in *Lyra* looks to us now, but its spectrum would not be that of a tenuous gas; it would be continuous, because the majority of the stars composing the galaxy give continuous spectra. Thus the spectroscope has put an end to such speculation with regard to the Ring Nebula in *Lyra*. It is not a galaxy of stars, but a body of gas at low pressure. In

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* Sir NORMAN LOCKYER, *Meteoritic Hypothesis*, MacMillan & Co., 1890.

after life HERSCHEL completely changed his views regarding the composition of nebulæ, thereby anticipating the results of modern spectroscopic investigation. He concluded that some of the more whitish of the nebulæ really were unresolved clusters of stars, but that many other nebulæ about which he detected a greenish tint were masses of gas, which the spectroscope has since shown them to be. The whitish nebulæ give continuous spectra, and Professor SCHEINER* has recently found that the continuous spectrum of the spiral nebula in *Andromeda* is crossed by absorption-lines as is the spectrum of sunlight. This does not prove that such nebulæ are really galaxies of stars, each of which is comparable to our Sun in magnitude, but it does not disprove it either, and Professor SCHEINER believes this to be the case. He thinks that the spiral nebulæ are all systems of stars, like the stars of our Milky Way. If this theory is correct, they must be hundreds of thousands of light-years distant from us.

It is the ringlike shape of this nebula which has brought it into prominence. Presuming that the law of the attraction of gravitation holds there just as it does in the solar system, how can the material composing the nebula assume this ringlike shape? Why does not the whole mass fall toward the center and form a great sphere or spheroid like the Earth or the Sun or one of the planets? It is not enough to assume, as we seemed to a moment ago, in speaking of the rotation of the ring, that this rotation will maintain its equilibrium. I mean to say that we cannot take it for granted that there is any velocity of rotation whatever which would maintain the equilibrium of the ring. The study of figures of equilibrium is one of the most difficult and at the same time the most interesting branches of theoretical astronomy. The problem is this: Given a mass of gas or liquid, each particle of which attracts each other particle, according to NEWTON'S law of gravitation, and the whole mass rotating, to find what shape it will assume. In particular, as applied to this case, could a mass of gas rotate with such a velocity that it would assume the shape of a ring? If so, then the ring is a figure of equilibrium. This problem has been discussed by mathematicians of note, among others LAPLACE, MAXWELL, and Madam KOWALEWSKI.

* SCHEINER, *Himmel und Erde*, Vol XI, p. 325.

MESSIER 51 IN *CANES VENATICI.*

BY J. E. KEELER.

Madam KOWALEWSKI has answered the question in the affirmative. She has shown that a mass of rotating gas or fluid may take the shape of a ring and maintain this shape, unless disturbed by some external force. It is probable, however, that such a ring of gas could offer very little resistance to an external disturbing force; and as such forces certainly do exist and act upon the nebula, it is possible that in a comparatively short time it will gradually break down and assume some other shape, perhaps spherical. In a comparatively short time, I say; but this does not mean a few weeks or a few years, but rather a few hundred thousand or million years. Such processes go on very slowly, and it is hard to set an upper limit to the time that would be required to effect such a transformation.

Perhaps, however, the explanation of the ringlike appearance is to be looked for in an altogether different direction. Possibly the ring does not rotate at all, and in that case each particle swings like a pendulum from one side of the ring to the other, passing rapidly through the center and lingering at the extremities of the swing as a pendulum does. Thus at any given instant most of the material would be in the ring, since each particle spends most of its time at the extremities of its swing. If this is the case, the ring will be quite stable, and will gradually contract into a compact mass without breaking up.

Many investigations have been undertaken in times past in the hope of detecting changes in the shape or brightness of nebulæ, or the motion of the whole or any part of a nebula, but without marked success. Drawings of the same nebula made twenty or thirty years apart differ greatly, even when both drawings are made by the same man; but in almost every case these differences have been found to be due not to changes in the nebula, but rather to changes in the men who made the drawings and in the telescopes with which they worked. Nebulæ are in general very hazy and indefinite objects, exceedingly hard to draw correctly, and the same nebula often presents different aspects as viewed in different telescopes. It is not to be wondered at, then, that a comparison of old drawings of any one nebula should show much diversity, but no reliable evidence of any change in the nebula. Professor HOLDEN, formerly Director of the Lick Observatory, has made an exhaustive historical investigation of the Great Nebula in

Orion, and from the mass of evidence which he collects and examines he can only conclude that certain parts of the nebula have changed in brightness, but that no motion has occurred in any part of the nebula.

There is a new instrument which is destined to be very useful in the study of changes which occur in the celestial landscape. It has been recently designed, and is now being made in the Carl Zeiss optical workshop in Germany. It is called the stereo-comparator, and is in principle a carefully and accurately made stereoscope. In the ordinary hand stereoscope we have before us in the frame of the instrument a piece of cardboard upon which are mounted two pictures; and we look with one eye at the one and with the other eye at the other. The stereoscopic effect of depth in the picture is due to the fact that the two pictures before us are not made from exactly the same point of view. They are made simultaneously by two lenses mounted a few inches apart, and when we look at the two pictures in the stereoscope, one with the one eye and the other with the other eye, we get the same perspective effect as if we were looking with our two eyes at the scene of the picture. So sensitive are the eyes to this stereoscopic effect that a distance of a few inches between the lenses of the stereoscope camera suffices to give depth to the picture, making the nearer objects seem to stand out clear in front of those behind. This is the principle of the stereo-comparator. It is an accurately made stereoscope, enabling the observer to look with one eye upon one photographic plate and with the other eye upon the other. The eye detects very quickly slight differences between the two plates and thus a quick and easy comparison may be made of two accurate pictures taken years apart. It is in the study of nebulæ perhaps that this instrument is at its best. The flocculent, streamy, or cloudy detail of a nebula which only confuses one who attempts micrometric measures would be especially favorable to the detection of a stereoscopic effect due to proper motion or rotation of the nebula or change in its shape.

The question as to the past history of the Ring Nebula in *Lyra* and the prospects of its future career remain to be considered briefly. Was it always a ring nebula, and will it always retain the shape of a ring, or is this only a transitional form

which has been recently assumed and will soon be abandoned? It is only by a comparative study of the observed forms of existing nebulæ that light can be gained on these points. Nebulæ present very diverse forms to our view. There are great diffuse nebulæ covering many square degrees of the sky and showing no definite outline; there are nebulæ of definite but very irregular shape; then there are spiral nebulæ, and ring nebulæ shading into planetary nebulæ by degrees so gradual that one is at a loss to draw a line of classification between the two. Diffuse nebulosity may be regarded as the earliest stage of nebular existence. The mutual attraction of the particles forming the nebula is very slight indeed, and contraction goes on very slowly. It is to be presumed, however, that these clouds are moving through space with velocities comparable with those of the stars: twenty or thirty miles per second. They are the winds of the heavens. The next stage is seen in such a nebula as Messier 8 in *Sagittarius,* which shows a tendency toward condensation. The form is irregular, and the mutual gravity of the particles forming the nebula is evidently not the predominant force. An attempt at condensation seems to have been frustrated, resulting in great irregularity of outline and the tearing asunder of the nebulous mass. The Trifid Nebula * is another case of the same sort. These dark lanes in the nebulosity are very curious. They are due perhaps to a collision of the nebulosity with a star, or rather to a star tearing through the nebula. One might at first imagine that the passage left by a star passing through a nebula would be closed up by particles of nebulosity rushing together in its wake, but this is not the case. It can be proven that the passage cleared by the star while passing through would not become narrower and gradually close up, but would get larger as time goes on. This process would not, however, continue indefinitely, because the attractive force exerted by the star while passing through, though powerful for the time being, is only temporary, and in the long run the effects of the temporary force would be obliterated by other weaker but ever-present forces. Thus it is to be expected that in the course of time these lanes will be closed up. The tem-

* See frontispiece to No. 74 of these *Publications.*

porary and fortuitous forces are now in the ascendency, but in the long run the weak but ever-acting force of the mutual attraction of the particles forming the nebula will gain the ascendency and the mass will assume a more regular form.

In the nebula in *Cygnus* the anarchistic forces seem to be triumphant. The nebula seems to have been struck by a celestial whirlwind and torn to shreds.

In the Great Nebula in *Orion* * we see evidence of a cataclysm befitting in its grandeur the magnificence of the stellar universe. Two nebulæ seem to have collided, and the débris of the conflict is scattered in the rear of the more powerful as it forces its way onward. The dark opening, somewhat resembling a fish's mouth, contains six stars, which are no doubt responsible for the disappearance of the nebulosity at this point. A dark lane such as we observed in the Trifid Nebula seems to be here in process of formation.

The spiral nebula, Messier 51 in *Canes Venatici,* shows the predominant action of the force due to the attraction of the central mass. One of the last, and perhaps the greatest, of the discoveries made by Professor KEELER was, that a large proportion of existing nebulæ have this spiral form.

Next in order comes the Ring Nebula in *Lyra,* and last planetary nebulæ.

We have traced the progression from the diffuse formless clouds of excessively faint nebulosity to the more dense irregular masses, and passed to the more regular spiral, ring, and planetary nebula. The slow process of contraction is not always left to take its course undisturbed, but it triumphs in the end.

The Ring Nebula may have been evolved from a spiral, or it may be a coördinate form, developed under more peaceful circumstances, where the force of the mutual attraction of the particles is not interfered with by disturbing influences from the outside. Perhaps the amount of rotational energy contained in the original mass is the deciding factor, slow rotation being favorable to the formation of a ring and rapid rotation favoring the spiral form. Professor SCHAEBERLE'S conclusion, that the Ring Nebula in *Lyra* is a closely-wound

* See frontispiece to No. 66 of these *Publications.*

It was designed to have a series of seven plates to illustrate the nebulæ referred to by Dr. NEWKIRK, but to our regret circumstances beyond our control made this impossible.—THE EDITORS.

spiral, has an important bearing on this point. However this may be, it is certain that the ring form is one of transition which will some day give place to one more stable. In ages to come the material composing the Ring Nebula in *Lyra* will gather itself together into a central sun, accompanied perhaps by a family of planets, and thus become a mature member of the family of the universe.

ASTRONOMICAL OBSERVATIONS IN 1903.

MADE BY TORVALD KÖHL, AT ODDER, DENMARK.

VARIABLE STARS.

Z Cygni. *

Jan.	1:	*Z* a little $<$ a.
	4:	midway between a and b.
	8:	one step $>$ b.
	19:	$=$ a.
Feb.	1:	$=$ b.
		$<$ b. $>$ c.
	20:	id.
	22:	id.
Feb.	25:	a little $>$ c.
May	27:	invisible.
Aug.	17:	$>$ d. $<$ c.
	21:	almost $=$ c.
Sept.	12:	$=$ b.
	23:	$=$ a.
	29:	id.
Oct.	20:	a little $>$ a.

S Ursæ majoris. †

Jan.	1:	S midway between e and f.
	4:	two steps $<$ e.
	8:	id.
	13:	one step $<$ e.
	19:	id.
Feb.	1:	$>$ e. $<$ d.
	15:	id.
	20:	id.
	22:	$=$ d.
	25:	one step $>$ c.
March	1:	one step $>$ d.
	22:	$>$ d. $<$ c.
	24:	id.
March	29:	id.
Apr.	2:	$=$ d.
	9:	id.
	14:	id.
	22:	two steps $<$ e.
May	27:	$=$ g.
Aug.	17:	three steps $<$ e.
	21:	id.
	22:	two steps $<$ e.
Sept.	10:	one step $>$ e.
	12:	id.
	19:	one step $<$ d.
	23:	id.
	25:	id.
	29:	id.
Oct.	18:	$=$ d.

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* *Vide* the sketch in the *Publications* A. S. P., No. 48, p. 69.

† *Vide* the sketch in the *Publications* A. S. P., No. 73, p. 56.

NEBULA N. G. C. 6992 IN *CYGNUS*.

BY G. W. RITCHEY.

(By courtesy of the Editors of the *Astrophysical Journal*.)